# Assessing the performance of manufacturing sustainability – a conceptual approach

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**Abstract:** Sustainability in manufacturing can be achieved through three sustainability components, namely economic, environmental and social. However, to develop a balance of strategy of each sustainability element is quite challenging if the sustainability practices not able to be assessed accurately. This most likely caused by the weaknesses in identifying the suitable mediators to support the implementation and assessment of the sustainability performances. In a proposed conceptual framework, six mediation aspects: design, material, process, quality, safety and competency are identified noteworthy in assessing the sustainability practices. Then, a total of 22 sub-mediators of economics, 18 sub-mediators of environmental and 23 sub-mediators of social competency are proposed to be integrated into the six mediation aspects as in a proposed conceptual framework. From the discussion, the information in this article can be used as a starting point to diversify the strategies through the quality-oriented mediators in assessing the performance of sustainability in manufacturing operations.

**Keywords:** manufacturing; sustainability; mediation aspect; performance assessment mediator; conceptual; framework.

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## 1 Introduction

The necessity of improving the performance of manufacturing sustainability (MS) is important in today's manufacturing environment. This is consistent with the needs to increase the level of competitiveness in dealing with the pressure of the rising costs in operations (Ziout et al., 2013; Schrettle et al., 2014). Multiplicity of plans and strategies have been widely developed to drive the adaptation of the sustainability concept in manufacturing (Jayal et al., 2010; Khalili-Damghani and Sadi-Nezhad; 2013). The ability to combine and strengthen the implementation of the MS practice through new ideas in innovation generates the advantage to contend competitively, primarily in enhancing the productivity and the marketability of the product (Voces et al., 2012; Sezen and Çankaya, 2013). A proactive action towards sustainability obviously can produce unlimited benefit in dealing with the crucial issues in ecological safety, as well as increase the returns on investment to meet the needs and opportunities of future markets in the modern paradigm of manufacturing (Tingström et al., 2006; Vinodh, 2010).

As a multi-dimensional concept, the focus on all components of sustainability must be balanced to ensure the allocation of financial investment and action is accordingly

adjusted. According to Despeisse et al., (2013), the level of sustainability can be accomplished through a substantial change, starting from behaviour to the use of technology in operations through a holistic approach. This potential can increase the efficiency of resource utilisation, and reduce the unexpected costs and other risks in manufacturing operations (Kuosmanen and Kuosmanen, 2009; van Passel et al., 2009; Vinodh and Jeya Girubha, 2012). This shows that the adaptation of the concept of MS is important. For this reason, the assessment of its implementation practices must be regularly executed. This is the only way to measure the performance of its implementation, as well as to strengthen and restructure the strategy employed to satisfy the aims of its implementation.

The objective of this article is to suggest, based on literature, the mediation aspect, mediators and its value of implementation, as well as the conceptual framework in assessing the performance of MS. The term of mediation aspect is used to categorise the contexts of practices, so as each of the practices can be well defined. In addition, mediation relations are generally thought of in causal terms (James and Brett, 1984), which is convenient in explaining the aims of this article. This is useful in formulating the action plan and strategies, and identifies fields of focus in improving the sustainability practices in manufacturing. This article starts with the introduction to the need to improve the sustainability in manufacturing. The second section explains the methods employed in this research. The discussion of each mediation aspect based on the identified mediator (a middle layer of practices in implementing and assessing each component of MS) is in the third section. This is followed by the discussion of the proposed conceptual framework in the fourth section. Finally, the conclusion and suggestions for future research are disclosed in the last section.

## 2 Materials and method

This study starts by exploring the information from several articles published related to MS from 2000 to 2014 in order to achieve the objective of this study. Initially, the review process is focused on identifying the main issues of MS, the framework in implementing the MS, elements of sustainability assessment, the method of analysis, findings and limitations in implementing the MS practice. Keywords such as 'MS', 'sustainability performance', 'sustainability indicators', 'sustainability measurement', and 'sustainability assessment' have been used for identifying and selecting the references on various databases such as Scopus, SciVerse ScienceDirect, Emerald, IEEE Explore, Google Scholar and so on. All articles are then filtered and sorted by relevance to the MS guided by the first research question as below:

Q1 What are the mediators that are frequently used in implementing and assessing the sustainability practices in manufacturing?

To answer this question, this study has focused on identifying practices that are often used in implementing sustainability in manufacturing. The frequencies of sustainable practice as mentioned in the literature are then recorded and classified based on the tendency against the three components of sustainability, namely economic, environmental and social competency. The classification is based on the definition as described in Table 1. Referring to the description of MS components as classified in Table 1, the reviewing process is further explored to identify the mediation aspect and the

mediators (the practices that mediate the implementation and assessment of MS) for each component of MS by asking the following questions:

Q2 What are the similarities among the mediators that have been mentioned by researchers?

Q3 What is the focus aspect to assess the sustainability performance in manufacturing?

Q4 What are the relationships between the findings?

**Table 1** Sustainability components and their description

| *Sustainability component* | *Description* |
|---|---|
| Economic | The classification was based on the tendency of the implementation value that used to reduce the operational cost and increase the productivity in manufacturing operations (Zhou et al., 2000; Awudu and Zhang, 2012; Ziout et al., 2013) |
| Environmental | The classification is referring to the activity implemented in controlling and reducing the adverse impact of operation, and the action implemented for environmental conservation (Voces et al., 2012; Schrettle et al., 2014). |
| Social competency | The classification was based on the development of actions in improving the quality of work environment, reduce and manage the risks, and impacts of physiological and psychological safety to the surrounding community (Labuschagne and Brent, 2005; van Bommel, 2011). |

Based on the above questions, the practices that mediate the implementation in each MS component are then grouped according to the mediation aspect of implementation such as design, material, process, quality, safety and competency. Next, each mediation aspect of implementation is then used in explaining how the performance of each MS can be assessed by referring to the mediation practices identified. This is followed by discussing the possible relationships that exist between the mediation aspect of implementation identified, and used to propose a conceptual framework in assessing the performance of MS.

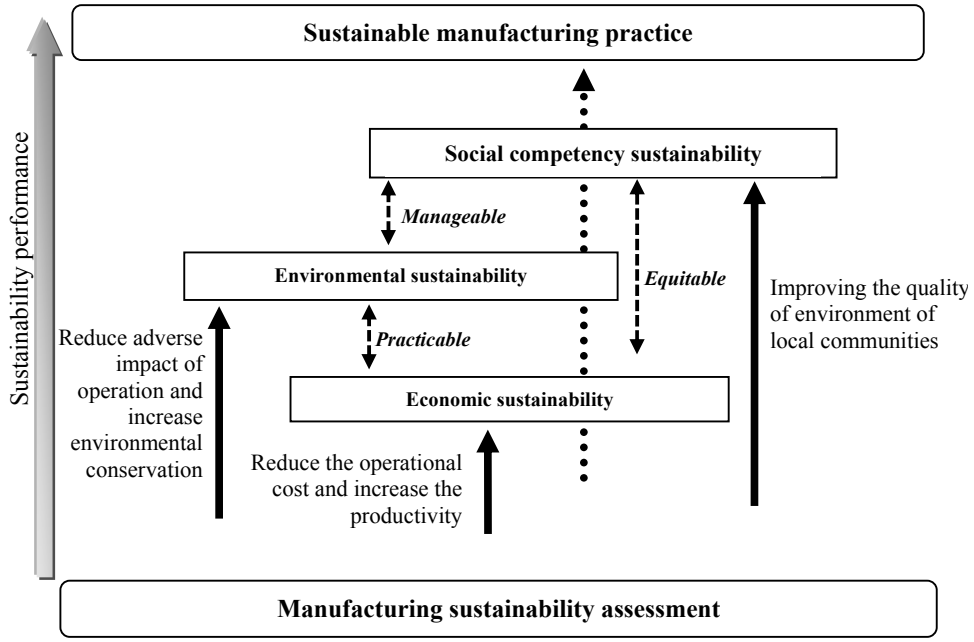
## 3 Mediation aspects in assessing the MS performance

The measurement and evaluation of MS performance is necessary in ensuring the strategy implemented is always monitored and assessed, especially in the early stage of product development (Labuschagne and Brent, 2005). This will help manufacturers to streamline the strategy implemented in achieving the aims of its implementation. In fact, the consistent evaluation against all components of sustainability enables to balance the focus, practice, investment required, and the equity of ownership in operations (Germani et al., 2014; Ghadimi and Heavey, 2014). This allows manufacturers to develop more realistic objectives and strategies in achieving a better sustainability performance in fulfilling the requirement of modern manufacturing paradigm (Khalili-Damghani and Sadi-Nezhad; 2013).

From the literature, it is understood that the economic sustainability assessment is valuable in analysing the influence of the strategy employed, and evaluates its implication to the financial performance in setting the rational target for each strategy

planned (Giunipero et al., 2012; Short et al., 2012; Ziout et al., 2013). The finding from literature suggests that the economic sustainability has a bilateral relationship with environmental sustainability through the value of what is practicable (the ability to execute the plan, strategies or practices to achieve the steady economic and environmental sustainability performance),and the social competency sustainability through the value of equitable (fairly in setting the action taken without any prejudice through a balanced focus on economic sustainability and social competency sustainability) as shown in Figure 1.

**Figure 1** MS practice




This noticeably affected the amount of investment that needs to be allocated (Ziout et al., 2013). The relation with the environmental aspect requires a sufficient budget to provide proactive action in environmental conservation (Sarkis, 2006). Meanwhile, the relations with the social sustainability will influence the strategy developed in underlying the safety of the surrounding communities, and providing a comfort and a conducive work environment for employees (Jayal et al., 2010; Vinodh, 2010; Vinodh and Jeya Girubha, 2012).

As in Figure 1, bilateral relationship between environmental sustainability with economic and social sustainability must be assessed to ensure the strategy implemented is always relevant to both (van Bommel, 2011). The interaction between the aspect of environmental sustainability and the aspect of economic sustainability should be guided by the value of what is practicable. From this focus, manufacturers can set the best practices in determining the strategy and investment amount required to plan, design and develop the most effective system for environmental conservation through a decent integration with the economic component (Ngai et al., 2013). According to Kaebernick et al. (2003), the environmental sustainability practice contributes 10% to the product costs and 1% of the re-manufacturing cost. Thus, the periodical assessment of sustainable

practice is required to produce better financial returns, in which the cost of management and environmental conservation cost can be reduced or maintained positively for a prolonged period of time (Prabawani, 2013; Iung and Levrat, 2014). The assessment of environmental sustainability also will influence the action taken to deal with the social issues. Through the value of what is manageable (the practices that are accomplished without creating a difficulty to be managed or controlled), manufacturers can investigate the impact of environmental management to social performance. It is giving a major influence in managing the production activity to avoid an adverse impact to the surrounding community (Sreenivasan et al., 2010).

The relation between social sustainability with economic sustainability and vice versa has been found to influence the value of equity ownership and level of interdependency between the organisation with surrounding communities (Zhou et al., 2000; Labuschagne and Brent, 2005; Sreenivasan et al., 2010; Giunipero et al., 2012). From literature, value of equitable can be initiated to balance the strategy of integrating the relationship between social and economic sustainability as shown in Figure 1. In the meantime, environmental sustainability performance has been found to highly influence the strategy used in dealing with issues in social sustainability, mainly to protect the social welfare of the communities involved (Kuosmanen and Kuosmanen, 2009). Therefore, the determination of the foundations that drive the implementation and assessment of the component of sustainability is essential (van Bommel, 2011; Vithayasrichareon et al., 2012; Schrettle et al., 2014). This will ensure the key strategy in fostering sustainability is achievable, and can be improved from time to time for the continuity of operations and business in the future. It is important to assist the business development in a competitive market environment (Vinodh, 2010).

### *3.1 Economic performance*

The economic performance assessment is often measured from the capital investment allocated in managing the operation in a conventional practice. However, in modern manufacturing paradigm, the economic performance is measured based on the aspect of sustainability. It is not only focuses on the amount of investment and financial strength, but also considers the influence of bilateral relationship with the social and the environmental components (Khalili-Damghani and Sadi-Nezhad; 2013). This successfully improved the capability to compensate the strength of capital investment to achieve aims, goals and competitiveness of business development. According to O'Brien (1999), the economic sustainability is important for developing countries, and typically becomes a major contributor to the gross domestic profit, foreign direct investment and income per capita from gross domestic profit (Vithayasrichareon et al., 2012). Thus, high economic performance commencing from the correct implementation and precise assessment in allocating the right capital investment is required in establishing the sustainability practice in manufacturing, without affecting the welfare of financial performance (Kuosmanen and Kuosmanen, 2009).

From the literature, four aspects of focus in product development, namely design (the consideration in designing the products), material (the identification of material to be used in products), processes (the activity in manufacturing or fabricating the products), and quality (product development plan and the aims of the organisation) can be used to mediate the implementation and assessment of economic sustainability performance. A

total of 22 sub-mediators were identified able to support this process as summarised in Table 2.

**Table 2** Mediation aspect and mediator of the economic aspect of sustainability

| *Mediation aspect* | *Mediator* |
|---|---|
| Design | Evaluate the investment risk [14], [18], [21], [23], [24, [27], [28] |
| | Easily disassembly products [5], [6], [9], [20], [26] |
| | Efficient utilisation of resources [15], [17], [18], [20], [22], [23], [28] |
| | Efficient utilisation of technology [11], [15], [17], [18], [20], [25], [26], [28] |
| | Increase the utilisation of common components in product design [20], [26] |
| Material | Materials and components purchased based on demand [19], [20], [26] |
| | Materials are purchased based on planning that documented [16], [25], [27] |
| Process | Minimise the production of failure products [1], [3], [5], [7], [22], [25] |
| | Establish standard operation procedures [16], [17], [18], [19], [24], [27] |
| | Increase technological innovative process [17], [24], [23], [25], [26], [28] |
| | Increase added value activities [3], [13], [21], [23], [27] |
| | Minimise transportation costs [5], [6], [19], [23], [25], [26], [27] |
| | Minimise production cost [2], [3], [9], [11], [15], [18], [20], [21], [25], [26] |
| | Increase the control of resource utilisation [19], [20], [22], [23], [26], [28] |
| | Reduce the non-added value activities [13] |
| | Reduce the total operation cost [2], [10], [15], [17], [18], [20], [21], [22], [27] |
| | Reduce the production lead time [6], [11], [15], [23], [26] |
| | Use renewable energy in production and transportation [18], [19], [22], [28] |
| Quality | Develop quantitative of quality objective [16], [17], [21], [23], [25], [28] |
| | Increase business image [2], [3], [4], [18], [20], [23], [25], [26], [27], [28] |
| | Increase the quality of product [1], [3], [5], [7], [22], [25] |
| | Redefine the market conditions for competitive advantages [15], [18], [27], [28] |

Notes: Authors: [1] O'Brien (1999), [2] Zhou et al. (2000), [3] Hon (2005), [4] Labuschagne and Brent (2005), [5] Tingström et al. (2006), [6] Byggeth et al. (2007), [7] Manley et al. (2008), [8] Kuosmanen and Kuosmanen (2009), [9] Jayal et al. (2010), [10] Sreenivasan et al. (2010), [11] Vinodh (2010), [12] Glover et al. (2011), [13] Glover et al. (2011), [14] van Bommel (2011), [15] Awudu and Zhang (2012), [16] Chen et al. (2012), [17] Ghadimi et al. (2012), [18] Giunipero et al. (2012), [19] Short et al. (2012), [20] Vinodh and Jeya Girubha (2012), [21] Vithayasrichareon et al. (2012), [22] Despeisse et al. (2013), [23] Hallstedt et al. (2013), [24] Khalili-Damghani and Sadi-Nezhad (2013), [25] Ngai et al. (2013), [26] Tseng et al. (2013), [27] Ziout et al. (2013) and [28] Schrettle et al. (2014).

In the design aspect, the mediation of risk assessment on investment encourages manufacturers to produce a better product to balance the invested amount at an earlier stage. Current market trends and the rising cost of operations (material and resource) were a significant input in this assessment. This may use to diversify an idea to produce a better product through a high focus to balance the cost to accommodate the demand of both parties (buyers and suppliers) in a difficult economic environment (Giunipero et al.,

2012). This will enhance the marketability of products and increase a better control on investment for the continuity of business in the future (Khalili-Damghani and Sadi-Nezhad; 2013). In addition, it will provide the opportunity for manufacturers to plan and restructure the strategy in ensuring the investment made is matched up with the sustainability performance featured. This includes the capital investment in new product development, improving the quality of existing products and infrastructure in streamlining the efficiency of manufacturing systems (Ziout et al., 2013).

The ability to design the product with the concept of ease of disassembly is the best mediator in implementing and assessing the economic sustainability performance (Sezen and Çankaya, 2013). This will encourage manufacturers to reconsider the level of product complexity involving manufacturing, assembly and maintenance operations. In terms of product lifespan, the ability to integrate ease of assembly methods is a must. It becomes more critical when products require periodic maintenance and component replacement in maintaining their function for prolonged periods of time (Germani et al., 2014). Several approaches such as simplifying the product structure in design (in terms of manufacturing and assembly complexity), and consideration of using common components from the existing products into new products will reduce the production costs and total investment costs (Jayal et al., 2010). The saving will allow the allocation of additional costs channelled to strengthen the use of new technology in product design, primarily in improving the efficiency of the design. Most of the latest technology in design, such as rapid prototyping, had provided the platform for preliminary analysis of design, especially in evaluating the complexity and reliability of design, the selection of materials, and the effectiveness of resource utilisation (Iung and Levrat, 2014).

The mediators that underlined under material aspects were found to influence the performance of planning and control on material utilisation. The implementation and assessment of these mediators allow manufacturers to plan and control the direct liability costs in operations such as inventory cost, material cost, maintenance cost, and transportation cost (Germani et al., 2014; Ghadimi and Heavey, 2014). The manufacturer also can re-organise the purchasing activities consistently with demand quantity. This will make the purchasing activity more efficient, and any financial losses can be prevented. This is because the buying quantity directly influences the cost of inventory (raw materials and unprocessed material). This will encourage manufacturers to improve the efficiency of purchasing activity, and determining the correct storage quantity to be at its most efficient level (Koplin et al., 2007; Giunipero et al., 2012). In addition, the close supervision of material requirements based on bill of materials also must be defined, determined and documented precisely. This is to ensure the material channelled to production line is in the right quantity, and fully utilised. Lack of supervision in controlling the material requirements tends to cause unnoticed financial losses, which eventually cause the operations to run at a loss if undetected (Schrettle et al., 2014; Xu et al., 2014).

The use of mediators mentioned in the process aspect will allow manufacturers to analyse the performance of the current manufacturing system and practices. As suggested in Table 2, these mediators not only focused on the processing activity, but also comprise support activities allied under this mediation aspect. This provides the opportunity for manufacturers to form the best strategy in enhancing the performance of operations and economic sustainability. Through these mediators, the assessment on work

procedures and work methods can be effectively implemented. This allows manufacturers to track any weaknesses in operating procedure. In addition, the operational standards also can be regularly reviewed, evaluated, and updated in ensuring the task can be consistently implemented. This provides room for improvement in allocating the resource in operations through comprehensive consideration of the total costs involved in supporting the manufacturing operations from time to time (Kuosmanen and Kuosmanen, 2009). This can avoid any dropouts of operational costs. The efficiency in implementing and assessing these mediators will provide a great influence on the performance of economic sustainability as the main milestone in aiming the development of sustainable practice in manufacturing.

As for the quality aspects, the stipulation of quality target as a mediator to execute the quality program in establishing the aspect of economic sustainability allows manufacturers to manage and control the strategy implemented with more effective (Ngai et al., 2013). This allows manufacturers set the realistic quality planning as a main option to drive the strategy planned on meeting the goal and objectives of financial management to achieve the desired economic sustainability performance. Through these mediators, manufacturers are encouraged to measure quantitatively the objectives in ensuring the activity undertaken is consistent with the prescribed quality target. It is also allowing the quality target constantly redefined (internally and externally). This systematically gives an opportunity for manufacturer to effectively manage and control the financial flows allocated in each operation, and set a better focus to remain competitive in a tough market environment. Additionally, it also drives manufacturers improve the quality and reliability of products. This tends to influence the image of manufacturers and the marketability of the product, as well as the overall financial performance (Sezen and Çankaya, 2013). The mediators that mentioned in Table 2 provide a broad dimension in increasing the profit, to regulate the capital investment, to set the value of expectation, redefine the investment structure, risk mitigation, reduce financial loss, and control the inflation level. It is significant in increasing the aspect of economic sustainability performance (Ziout et al., 2013).

### *3.2 Environmental performance*

From the literature, the aspect of environmental management performance has a close relationship with the company performance, especially in expanding business opportunities (Ngai et al., 2013). According to Schrettle et al. (2014), the need of environmental management has been increased along with the awareness to protect the impact of the manufacturing operations to the environmental. This urges manufacturers to reconsider the business model, and restructure the manufacturing operations to be more efficient and environmentally friendly (Culaba and Purvis, 1999; Koplin et al., 2007; van Bommel, 2011; Voces et al., 2012; Iung and Levrat, 2014). It may vary between organisations depends on the business nature and size of organisations. As stated in Table 3, the implementation and assessment of environmental sustainability performance also can be executed through four aspects of performance measurement (design, material, process and quality). The 18 mediators were identified from the literature, and can be used to assess the environmental sustainability performance as tabulated in Table 3.

**Table 3** Mediation aspect and mediators of environmental aspect of sustainability

| *Mediation aspect* | *Mediator* |
|---|---|
| Design | Use recycled materials in product design [2], [4], [6], [7], [10], [11], [18], [21], [27] |
| | Embedded recycled material in designing the processes [6], [7], [12], [20], [27] |
| | Use eco-friendly material in product design [6], [11], [19], [24], [28], [29] |
| Material | Use easily degradable chemicals [7], [8], [11], [16], [21], [28] |
| | Use recyclable, reusable and non-toxic materials [2], [6], [7], [10], [11], [18], [23], [24] |
| | Use of renewable material [1], [3], [7], [10], [14], [18], [19], [23], [28] |
| | Use recycle packaging materials [1], [4], [18], [27] |
| Process | Evaluate the direct environmental effect from the operation [25], [26], [27], [28], [29] |
| | Established waste reduction and energy efficiency programs [23], [26]. [27], [28] |
| | Reduce emission of substances and control [14], [16], [18], [22], [24], [26], [27], [28], [29] |
| | Minimise transportation [6], [7], [20], [24], [26], [27], [28] |
| | Reduce the waste of materials [3], [9], [10], [16], [18] |
| | Increase the recycling activity [4], [6], [15], [19], [20], [27], [28] |
| | Reduce energy consumption [1], [2], [3], [4], [10], [11], [14], [16], [17], [22], [26], [28] |
| | Increase the opportunities of preventing pollution [3], [8], [18] |
| Quality | Establish environmental management and control [1], [6], [10], [12], [14], [15], [18], [19] |
| | Establish material and energy consumption reduction program [12], [14], [20], [23] |
| | Pollution prevention and reduction control [1], [2], [3], [8], [14], [18], [22], [26] |

Notes: Authors: [1] Culaba and Purvis (1999), [2] O'Brien (1999), [3] Zhou et al. (2000), [4] Hon (2005), [5] Labuschagne and Brent (2005), [6] Tingström et al. (2006), [7] Byggeth et al. (2007), [8] Manley et al. (2008), [9] Kuosmanen and Kuosmanen (2009), [10] Jayal et al. (2010), [11] Sreenivasan et al. (2010), [12] Vinodh (2010), [13] Glover et al. (2011), [14] Glover et al. (2011), [15] van Bommel (2011), [16] Awudu and Zhang (2012), [17] Chen et al. (2012), [18] Ghadimi et al. (2012), [19] Giunipero et al. (2012), [20] Short et al. (2012), [21] Vinodh and Jeya Girubha (2012), [22] Vithayasrichareon et al. (2012), [23] Despeisse et al. (2013), [24] Hallstedt et al. (2013), [25] Khalili-Damghani and Sadi-Nezhad (2013), [26] Ngai et al. (2013), [27] Tseng et al. (2013), [28] Ziout et al. (2013) and [29] Schrettle et al. (2014).

In the design aspect, three mediators, namely the use of recycled materials in product design, embedded recycled materials in designing the processes, and the use of eco-friendly materials, were identified to have a significant value in implementing and assessing the performance of environmental sustainability. According to Anastas and Zimmerman (2003), the appropriate up-front designs permit to reduce the environmental impacts in creating a sustainable product, process, or system. From side to side, the use of recycled materials in product design allows manufacturers to reduce the dependency on new materials in manufacturing the product (Fiksel et al., 1999). In fact, through the right quantity, the material costs and processing costs can be minimised. This can reduce the disposal of waste; thereby reducing the pollution to the environment (Vinodh, 2010).

However, the percentage of recycled materials to be used must be balanced to ensure it does not produce an adverse impact on the consumer, or affect the quality of products (O'Brien, 1999). This is because the composition of recycled materials normally can change after reprocessing, and if the composition is not controlled, it is potentially harmful with an adverse impact to users' safety and health. Thus, it must be evaluated at the early stage of product development to fulfil the safety and quality standard prescribed.

The awareness to manufacture the product using environmentally friendly materials also can minimise the environmental pollution (Byggeth et al., 2007). The consideration to increase the use of environmentally friendly material such as bio-degradable materials in the product or process has successfully formed new paradigm in environmental care through green engineering (Anastas and Zimmerman, 2003; Kaebernick et al., 2003). This can be accomplished through early planning which is made during the design stage. Therefore, the ability to use these mediators to support the aspect of environmental sustainability is crucial. This will influence every action taken to develop the best practice to achieve a better environmental sustainability performance.

For the mediation aspect of design and material, these aspects contain the important mediators that produce a massive impact on environmental performance. The responsiveness to increase the design efficiency by increasing the use of bio-degradable materials will minimise the pollution and reduce the material disposal costs. In fact, it can reduce the impact of soil degradation and loss of biodiversity to the environment (Awudu and Zhang, 2012). The willingness to replace the material with non-toxic materials even with a slight increase in cost will have a major impact on environmental management. This can reduce the harmful effects of products or processes on human health and the environment, either during processing or disposal (Manley et al., 2008). Through the efficiency in design, the use of existing materials also can be increased. The design consideration to use recycled and reusable materials or components in new or existing products, as well as packagings can reduce the dependency on new material, reduce the cost and minimise waste generated (Sreenivasan et al., 2010; Vinodh and Jeya Girubha, 2012). Thus, the focus on these mediators (for implementation or assessment) not only increases the chances to incorporate the environmental sustainability in operations, but also paves the way for manufacturers to assess the contribution of environmental sustainability practices in increasing the level of MS performance (Short et al., 2012).

Meanwhile, the mediator that classified under mediator aspect of process provides a wide space for manufacturers to improve the aspect of environmental sustainability at the processing stage. The environmental issues in manufacturing operations are an outcome of the manufacturing process, either directly or indirectly (Salonitis and Ball, 2013). Within this aspect, the evaluation of the direct environmental effect of manufacturing operations is an effective mediator to assess the achievement of the environmental sustainability aspect. This will prompt the action taken in setting the strategy for dealing with environmental issues. Based on the 12 principles of green engineering by Anastas and Zimmerman (2003), the specific practices in process must be emphasised to achieve the environmental sustainability aspect in manufacturing operations. In fact, in the second principles it is clearly mentioned that preventing waste is better than treating or cleaning up waste after it is formed. Therefore, waste reduction and energy efficiency programs are no stranger to be used as the mediator under this mediation aspect. This allows manufacturers to develop a promising strategy to achieve the aspect of environmental sustainability (Culaba and Purvis, 1999; Sreenivasan et al., 2010; Iung and Levrat, 2014). In addition, through a strong correlation with the design aspect, the focus on this mediator

provides the best platform to channel the information in evaluating and improving the effectiveness of the strategies used in processing activities.

The interaction of environmental control elements such as environmentally friendly operations, reduction of resource consumption, and minimisation of processing waste not only becomes the key element in environmental management, but also can increase the performance of safety, and improve the personnel health (Jayal et al., 2010; Ghadimi and Heavey, 2014). According to Ghadimi et al. (2012), the assessment of pollution levels and operational impact on greenhouse must be emphasised to strengthen the environmental management practice. In addition, the consistent action in assessing the mediators used in waste reduction programs, energy efficiency and pollution emission control was among the indicators that must be streamlined in promoting the sustainability practices in manufacturing (Voces et al., 2012). In fact, Tseng et al. (2013) has suggested that the resource management activities driven by environmental sustainability are necessary to maintain the sustainable competitive advantage. This can be outlined through the implementation of eco-labelling, the adaptation of ISO 14001, and strengthening the compliance of environmental laws and regulations as a guideline in setting the activities in manufacturing operations (Koplin et al., 2007; Hallstedt et al., 2013).

As for the quality aspect, the assessment of environmental management performance, material reduction programs, energy consumption programs, and pollution control strategies is an important mediator in environmental sustainability practice. It not only has allowed visions and mission of environmental management constantly reviewed and updated, but also is useful in assessing the suitability and the effectiveness of environmental management policy (Awudu and Zhang, 2012). This allows manufacturers to develop a more specific environmental policy, and encourages the more dynamic practice to respond to the changes in the manufacturing environment (Culaba and Purvis, 1999; Tseng et al., 2013). This includes the formation of strategies to address the rising cost of natural resources, fulfilling the government mandates, and strict environmental management regulations (Ziout et al., 2013). According to Giunipero et al. (2012), the ability to measure, evaluate and improve environmental management will create greater opportunities in enhancing competitive advantage. This is consistent with the market pressures and demands that concentrate on producing environmentally friendly products (Byggeth et al., 2007; Duin and Thoben, 2011; Iung and Levrat, 2014). Moreover, the changes in modern manufacturing paradigm have urged manufacturers to proactively implement the environmental management system. Its implementation must cover the aspects of management and impacts on environmental and customers (internally and externally). However, the allocation of cost in dealing with the environmental issues should be wisely addressed in establishing the best environmental sustainability practice (Tingström et al., 2006).

### *3.3 Social competency performance*

The integration of social and ecological impacts should be corresponding with business perspective in establishing the social sustainability in manufacturing (Byggeth et al., 2007; Khalili-Damghani and Sadi-Nezhad, 2013). According to Vithayasrichareon et al.

(2012), social sustainability is the foundation needed by humans to improve the quality of life. Currently, several strategies implemented potentially produce the opposite impact against social sustainability, although successfully improve the performance of economic and environmental. Therefore, the development of business strategy needs to focus not only on economic and environmental aspects, but also on social aspects, which need to be balanced with full of accountability (Kuosmanen and Kuosmanen, 2009; van Passel et al., 2009). The ability to address the concern over the social sustainability from the context of populations, urbanisation and human development can increase the acceptability of organisations by the local community and enhance the marketability of products (Zhou et al., 2000; Glover et al., 2011). Thus, the mediators that influence the social sustainability should be understood. This can provide value added to the business function, primarily in fulfilling the needs of populations and market demand (Voces et al., 2012). From the literature, a total of 23 mediators was identified and can be referred in implementing or assessing the performance of social sustainability. These mediators are classified into five aspects of implementation: design, process, quality, safety and competency as stated in Table 4.

As stated in Table 4, the mediators classified in the design aspect can provide the substantial platform to formulate the best strategy to achieve the best social sustainability practice. As a key element in product development, strong focus on these mediators allows manufacturers to determine the most efficient production orientation without affecting the ecosystem and the surrounding communities (Fiksel et al., 1999; Byggeth et al., 2007; Voces et al., 2012; Vadoudi et al., 2014). This will provide a valuable input in formulating the comprehensive framework to integrate the social sustainability into business practices (Koplin et al., 2007). These mediators may be used to investigate the impact of design on the surrounding communities (internal or external), work organisation, work layout, personal comfort, product performance, marketability, and product life. It can increase the positive perception of customers, and the added value obtained from social sustainability practice in design can expand the product market, increase product acceptance level, and reduce the indirect impacts to the social communities and the environment (Awudu and Zhang, 2012).

The mediators in the processing aspects focused on the integration and involvement of employees in manufacturing operations. This should be undertaken with careful consideration since it will influence the integration between employees and manufacturing system. This awareness will help manufacturers determine the required process flow with more efficiency through the development of operation standards in organising the process more systematically (Glover et al., 2011; Prabawani, 2013). The periodic evaluation of these mediators must be maintained at a high stability level. It becomes even more critical when involving manual or semi-automation operation. This is because the changes of work capacity are something that cannot be avoided, especially in dealing with the fluctuation of demand. The assessment of these mediators may help to balance the changes of work capacity. Moreover, the consideration of the physiological and psychological impact will influence the acceptance level of employees against any changes in operation (Hon, 2005; Vinodh and Jeya Girubha, 2012; Iung and Levrat, 2014). This will increase the level of manufacturing flexibility in stabilising the manufacturing operations (Despeisse et al., 2013; Sezen and Çankaya, 2013; Schrettle et al., 2014).

**Table 4** Mediation aspect and mediator of social competency aspect of sustainability

| *Mediation aspect* | *Mediator* |
|---|---|
| Design | Minimise the effect of safety and health in the community [3], [5], [8], [10], [21], [24], [29] |
| | Improve reliability of components in product [7], [11] |
| | Improve working conditions [13], [17], [24], [26] |
| | Increase product durability [7] |
| | Improve comfortability of work environment [17], [24] |
| Process | Consider the workforce engaged in the process [2], [6], [13], [17], [18], [21], [23], [24] |
| | Use electronic communications and document transfer [3], [4], [5], [6], [7], [17] |
| | Consider the previous and common experience in operation [6], [15], [22], [24], [26], [29] |
| | Rearrange process to reduce queuing time [7], [12], [16], [24], [27] |
| | Improve the manufacturing capability [1], [2], [3], [11], [12], [21], [29] |
| | Readiness to adapt with process flexibility [1], [4], [6], [7], [12], [16], [22], [29] |
| | Improve the movement of operation flow [4], [13], [15], [16], [23] |
| | Develop standards of process to establish the consistency [6], [13], [22], [26] |
| Quality | Establish environmental policy statements [2], [5], [6], [16], [19], [20], [24], [27], [29] |
| | Increase strategic alliance with organisational strategies [4], [8], [10], [15], [17], [25], [29] |
| | Increase employee motivation [2], [6], [14], [17], [18], [20], [23], [24], [26], [28] |
| Safety | Improve housekeeping practices, work conditions and labour safety [15], [17], [18], [21] |
| | Compliance with the environmental and safety regulation [1], [2], [6], [14], [19], [28], [29] |
| | Improve labours safety in operation [2], [5], [8], [10], [16], [17], [18], [20], [21], [24], [28] |
| | Collaboration with communities, governments and non-governments regarding environmental issue [5], [8], [14], [15], [16], [19], [27], [28] |
| Competency | Improve process innovation [8], [10], [13], [15], [21], [24], [26], [27], [29] |
| | Increase the operation efficiency [2], [4], [8], [9], [21], [26], [28], [29] |
| | Increase the production productivity [2], [4], [8], [10], [11], [17], [26], [27], [28] |

Notes: Authors: [1] Culaba and Purvis (1999), [2] O'Brien (1999), [3] Zhou et al. (2000), [4] Hon (2005), [5] Labuschagne and Brent (2005), [6] Tingström et al. (2006), [7] Byggeth et al. (2007), [8] Manley et al. (2008), [9] Kuosmanen and Kuosmanen (2009), [10] Jayal et al. (2010), [11] Sreenivasan et al. (2010), [12] Vinodh (2010), [13] Glover et al. (2011), [14] Glover et al. (2011), [15] van Bommel (2011), [16] Awudu and Zhang (2012), [17] Chen et al. (2012), [18] Ghadimi et al. (2012), [19] Giunipero et al. (2012), [20] Short et al. (2012), [21] Vinodh and Jeya Girubha (2012), [22] Vithayasrichareon et al. (2012), [23] Despeisse et al. (2013), [24] Hallstedt et al. (2013), [25] Khalili-Damghani and Sadi-Nezhad (2013), [26] Ngai et al. (2013), [27] Tseng et al. (2013), [28] Ziout et al. (2013) and [29] Schrettle et al. (2014).

The utilisation of electronic communications tools and electronic document transfer as the mediators to support the manufacturing operations can increase the efficiency of information dissemination within a manufacturing environment (Koplin et al., 2007; Vadoudi et al., 2014). This can eliminate miscommunication and avoid the conflicts between employees and management at production floors (Tseng et al., 2013). As a result, manufacturing activities can become more transparent, productivity can be increased and social sustainability performance can be improved (van Bommel, 2011).

As for the quality aspects, three mediators consist of the establishment of an environmental policy statement, increasing the strategic alliance with operational strategies, and increase employee motivation identified can be used in assessing the impact of quality management on the social sustainability performance. The clear and consistent environmental policy statement with the operation executed has strong influence in determining the work contents to be implemented (Koplin et al., 2007). The environmental policy assessment that in line with the real time project is essential in developing a guideline to formulate an effective operational strategy. Even, it can enhance the safety level, quality and performance of operations (Labuschagne and Brent, 2005). This mediator not only allows manufacturer to validate the effectiveness of policy, but also allows manufacturers to re-construct the suitable formation of policy to protect the interests of the community in the organisation either through a defensive or offensive action (van Bommel, 2011). It is useful in strengthening the strategy to deal with any issue that arise inside and outside the organisation. It is also will ensure the strategic cooperation is consistent with the organisational missions. Any difficulty identified from these mediators can be used to develop an appropriate action with more transparent and systematic. This makes the social sustainability practice in operations becomes more meaningful to the surrounding communities, although it has received less attention than economic and environmental sustainability (Hallstedt et al., 2013). In addition, the implementation and assessment of these mediators will ensure the perception of each entity in the organisations always being prioritised. This will produce a significant impact on manufacturing ecosystem, and provide a space to motivate the employees to positively adapt to the changes made to implement best practice in MS (Giunipero et al., 2012).

Short et al. (2012) stated that the compliance performance against laws and regulations on labour, environmental, health and safety is a part of action required in establishing the MS practice. However, the orientation of safety concern is varied based on a business concept, process and category of product yielded (Vinodh and Jeya Girubha, 2012). Readiness to consider the safety concern as the mediator in establishing the social sustainability practice is needed to protect the social welfare of employees and the local community. This is necessary to improve work safety, working environment, and level of housekeeping practice, so that the working environments are favourable, mainly to enhance the ability to hire local employees (Ziout et al., 2013). The integration between technology and the safety concerns also potentially improves the operational efficiency, and reduces the reliance on manual operations. This will improve the level safety compliance and provide a safer work environment, as well as improve the quality of work environment. This consequently contributes to the cost reduction in managing the safety concern and increase the level of operational productivity (Jayal et al., 2010). Moreover, the collaboration level between the organisation with the community, government and non-government in dealing with the environmental issues and safety concerns will increase the social responsibility performance, and increase the recognition

of the surrounding community with the existence of the organisation (Manley et al., 2008; Prabawani, 2013). Through these mediators, manufacturers can develop more effective strategies to deal with social safety of local communities in ensuring the continuity of business operation can be maintained for long periods of time.

As for the competency aspect, the mediators identified can provide useful information in assessing the impact of the strategy implemented on social performance. Manufacturers can also assess the competency level of employees and management required to support the process of innovation, increase operational efficiency, and improve the operational productivity (Schrettle et al., 2014). All these indicators are closely related to social performance. The quality of work, level of knowledge and qualification must be underlined in adapting these mediators in manufacturing operations for better results (Fiksel et al., 1999; Tingström et al., 2006; Awudu and Zhang, 2012). This consequently allows the manufacturer to assess the willingness of employees to engage with the innovation activity planned, primarily to make sure the desired output and the aim of its implementation are achievable. In addition, it can provide the evidence of competency and adaptability level of the operations. This further allows manufacturers to plan and develop the best strategy in ensuring the employees have a consistent focus on work performed to increase the operational productivity, comprehensively (Yusup et al., 2013).

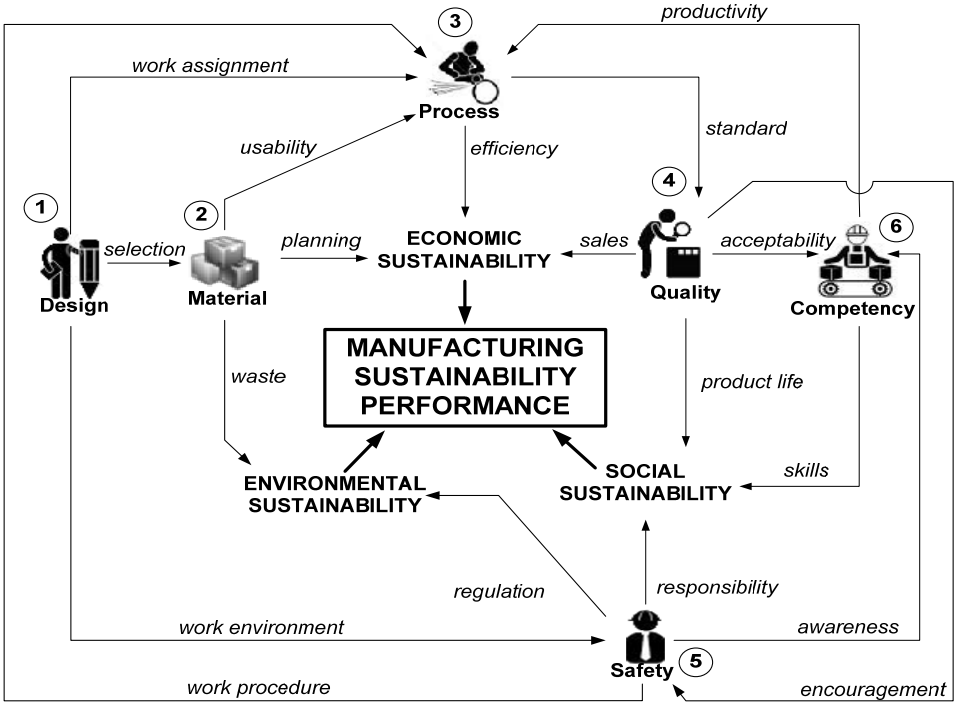
## 4 Conceptual framework in assessing MS performance

Based on the discussion in the previous section, the assessment of all three components of sustainability in manufacturing can be executed through the focus on six mediation aspects of implementation, namely design, material, process, material, quality, safety and competency. From the discussion, all six mediation aspects that highlighted in this article found to have a multilateral relationship with each other's in strengthening the performance of MS as illustrated in Figure 2. Through the focus and the tendency of each of the mediators identified, the ability to integrate all these aspects either through the offensive or defensive strategy allows manufacturers to execute a transparent assessment in a systematic way to achieve the aim of its implementation.

Based on Figure 2, the assessment of the MS begins as early as the design stage. The assessment is normally used to predict and determine the strategy that can be executed to address the potential of risks in dealing with the competitive market environment. This will help manufacturers strengthen the strategy to improve the benefit of operations encompassing three components of the MS comprising the economic aspect, the environmental aspect and the social competency aspect in manufacturing operations. From the literature, the achievement of economic sustainability can be measured by assessing four mediation aspects encompassing design, material, process and quality. The assessment in design provides the input to strengthen the strategy in planning to control the financial flows, lower the operating costs, and increase return on investment (Byggeth et al., 2007; Hutchins and Sutherland, 2008; Hallstedt et al., 2013; Sezen and Çankaya, 2013). The focus of assessment in design aspect must emphasise the 'selection' of proper material, the 'usability' of material that can be optimised in processing, and the 'planning' of proper material requirement will provide an opportunity for the

manufacturer to plan and control the use of materials in an orderly manner. The aim of this link is to ensure the use of materials can be planned in the early stage of design, so that the use of materials can be maximised in a more effective way to avoid any financial loss. By referring to the mediation aspect of process, the assessment on the standard used in processing activities through the linkage elements of 'work assignment' in setting the work processes, the 'efficiency' in setting the value added activities, the focus in improving the 'productivity' of operations, and establishing the 'standard' operation procedures along with the accurate guidelines will improve the processing efficiency, and increase the ability to produce better quality products with the right costs. Meanwhile, the links element of 'sales' and 'product life' are proposed to be integrated in assessing the mediation aspects of quality. The idea of this link is to measure the operational efficiency, the level of acceptability, and the reliability of products by the customer. Customers are becoming more sceptical with the product in the market (Short et al., 2012). Therefore, manufacturers must be aware of the customer appreciation value of the product, so as joint efforts can be integrated to achieve the sustainability in economic aspect (Seuring and Gold, 2013). Additionally, this is to ensure the marketability of the product can be enhanced, and generates a better profit, which contributes to achieving the aspect of economic sustainability (Sezen and Çankaya, 2013).

**Figure 2** Conceptual frameworks in implementing and assessing the MS performance




As for environmental sustainability, the 'waste' and 'regulation' are the two links elements connected to the mediation practices that are underlined in assessing the mediation aspects of environmental sustainability. This can be executed through the evaluation of the effectiveness in controlling the waste produced and the ability to integrate the environmental regulations in manufacturing operations, as well as the

compliance level of the law and regulation for environmental conservation. In strengthening the assessment aspect of environmental sustainability, four mediation aspects, namely design, materials, process and quality are proposed to be emphasised in developing the strategy to assess the performance of environmental sustainability. In assessing the efficiency of the strategy employed, the assessment should be focused on the ability to optimise the use of existing material, and reduce the dependency on new material in manufacturing the product. The use of the link elements, namely 'selection', 'usability' and 'planning' as a mediator to control the use of material can provide the biggest contribution in increasing the efficiency of environmental management performance. Through the proper considerations, the waste stream associated with the design, processes, use and/or disposal of materials can be reduced or eliminated (Sezen and Çankaya, 2013).

Moreover, the assessment of strategies in managing the production wastes is able to produce a direct relationship with environmental performance. Through the optimisation of production processes along with production functions, waste and pollution can be reduced (Xu et al., 2014). This potentially influences the design efficiency in material selection for product development. The use of the link element of 'usability' between the mediator aspects of material and processes that focus on material utilisation in processing activity, and the use of the link element of 'encouragement' between the competency and safety in improving the quality of environment can provide the wide space to access the current practice that related to environmental. All this value is useful in developing the strategy to control the waste, pollution, and increase the conservation activity on the environment to the entire ecosystem in manufacturing.

Meanwhile, the assessment for the aspect of social competency sustainability, the proposed conceptual framework emphasised five mediation aspects encompassing the focus on design, process, quality, safety and competency. Simultaneously, indirect effects on social competency performance can be evaluated through the convergence in the process. The assessment of the design aspects produces a direct relationship with safety practice. The competency in integrating the safety concerns is now a well recognised need for achieving overall sustainability in manufacturing activities (Jayal et al., 2010). The use of links element of 'work environment' intentionally used to describe the engagement of the design aspect to the safety aspect, and to connect with the mediator identified in the previous section. As for the mediation aspect of competency, the 'acceptability' is used to be linked to the quality aspects, and the use of links element of 'awareness' is used to be linked with the safety aspect. This was based on the nature of both aspects that should be reflected by the willingness of employees in performing their works. In achieving the aspect of social competency sustainability, the involvement of employees in manufacturing activities is required (Yusup et al., 2015). This explains why 'skills' are used as the link element to depict the effect of competency aspect to the sustainability aspect of social competency. Additionally, this can guide the assessment of safety and health performance, which significantly contributes in supporting the establishment of the comfortable and safe work environment. Furthermore, the assessment of process aspects will provide a meaningful input in assessing implementation value in the quality.

In the meantime, the 'standard' and the 'productivity' were used as the link elements between the mediation aspects of process and quality, and between the aspects of

competency and processes. This is useful in assessing the engagement level of the employees in processing activity. This assessment will disclose the focus and the consistency level of employees in completing the task. The consideration of physiological and psychological indicators is useful in assessing the effects of the mediators in the sustainability aspect of social competency. The results from this assessment are beneficial for manufacturers as an input to improve the work environment, increase the acceptability level of the employees with the changes in operations procedure, enhance the level of flexibility in production, and encouragee the employees to improve the competency level in performing the task. According to Hon (2005), because of the nature of human psychology, employees will generally improve what is measured and assessed, and sometimes will improve what is measured without improving the underlying performance that is sought. Therefore, the assessment that is based on responsibilities and accountability can provide a comprehensive overview on the sustainability aspect of social competency. This can not only improve the operational efficiency, but also strengthen the acceptability of the surrounding community in maintaining the continuity of the business in future.

## 5 Conclusions and future research

As for the conclusion, four mediation aspects comprising design, material, process and quality can be employed in developing the strategy to assess the economic sustainability performance. In the economic pillar, a total of 22 mediators were highlighted in this article. These mediators are driven by the focus in reducing the operation cost through the efficient utilisation of material and resources. For environmental sustainability, a total of 18 mediators were identified. It emphasises driving and supporting the activity in assessing, maintaining and monitoring the environmental performance. All mediators discussed in environmental sustainability suggest focusing on enhancing the capability of resource utilisation, reducing the use of new material, minimising waste in operations, and reducing the pollution emission to the environment. It is beneficial in controlling the impact of operation to the environment and increases the formation of environment conservation strategy. In social sustainability, the five mediation aspects of design, process, quality, safety and competency were suggested. It was based on the key focus in controlling the operation to reduce the negative impacts of operations on the surrounding communities. A total of 23 mediators were identified to support the establishment of the strategy in streamlining the assessment of the social competency aspect of sustainability.

For future research, mediators that used in developing the proposed conceptual framework from each mediation aspect will be tested to validate the influence of the mediator in assessing the performance of sustainability in manufacturing. Questionnaire survey will be employed as a primary source in collecting the information for analysis. Data from the empirical study will be analysed in streamlining the proposed framework to be more robust in assessing the MS performance. The finding is believed to be useful in balancing the action implemented in strengthening the strategy to improve the level of sustainability in manufacturing.

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